**PATHFINDER**

# HIGH-ENERGY AEROBRAKING PROGRAM PLAN

**December 1988**

Office of Aeronautics and
Space Technology

National Aeronautics and
Space Administration
Washington, D.C. 20546

# FOREWORD

Pathfinder is a research and technology initiative by the National Aeronautics and Space Administration (NASA) which will strengthen the technology base of the United States civil space program and provide options for potential future space exploration missions. These missions may include an intensive study of the Earth, a return to the Moon, piloted missions to Mars, or the continuing robotic exploration of the Solar System. Pathfinder is managed by the NASA Office of Aeronautics and Space Technology, to advance critical technologies for these missions and ensure technology readiness for future national decisions regarding exploration of the Solar System. Pathfinder extends the technological foundation being established by the Civil Space Technology Initiative, which focuses on advancing a family of technologies for transportation to and operations in near-Earth orbit and supporting science activities. Pathfinder looks toward longer-term missions beyond Earth orbit and into the Solar System.

Four major thrusts of Pathfinder are Surface Exploration technology, In-Space Operations technology, Humans-in-Space technology, and Space Transfer technology. The Space Transfer thrust will provide the critical technologies needed for transportation to, and return from the Moon, Mars and other planets in the Solar System. A key element of this thrust is the High-Energy Aerobraking Program which will provide the technology base required to perform high-velocity aerocapture and aeromaneuvering, with resultant substantial reductions in mission LEO mass requirements.

This Program Plan describes the goals and objectives, management plan, technical approach, resources and financial management plan, facilities plan and technology transfer planning for the High-Energy Aerobraking element of Pathfinder. For additional information on the High-Energy Aerobraking Program, please contact:

NASA Office of Aeronautics and Space Technology,
Aerodynamics Division
Washington, D.C. 20546
Phone Number: (202) 453-2820

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# SECTION 1

# EXECUTIVE SUMMARY

## 1.1 Program Goals & Objectives

The long-term goal of the Pathfinder High-Energy Aerobraking Program is to develop and experimentally validate key technologies that will enable the use of aerobraking for robotic and piloted missions to Mars and other related planetary exploration missions. In this program, emphasis will be place on the development of advanced, computational techniques and validation of these techniques to the extent possible through ground-based experimentation. The definition and conduct of flight tests will provide verification of all key, high-energy aerobraking technologies.

## 1.2 Organization and Management

The High-Energy Aerobraking Program will be planned and implemented in two broadly defined phases. Phase I will be a research and technology development phase. It will result in the definition of selected aeroassist vehicle concepts and the definition of flight experiments. (Phase I falls within the next five years, FY 1989 through FY 1993, and was budgeted in the FY 1989 Pathfinder Program Plan.) Phase II is projected as a technology demonstration phase, culminating in an appropriate aerobraking flight experiment(s). Figure 1.1 provides the program work breakdown structure (WBS).

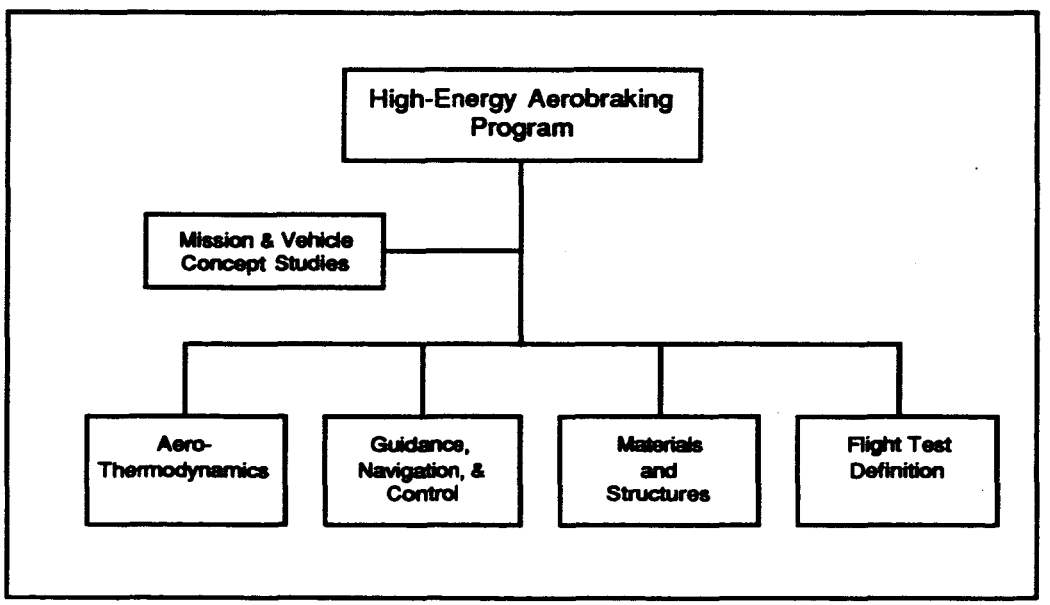


Figure 1.1 Pathfinder High-Energy Aerobraking Program Work Breakdown Structure

The High-Energy Aerobraking Program will be managed by a Program Manager in the Aerodynamics Division (RF) of the Office of Aeronautics and Space Technology (OAST). Coordination between the various discipline efforts within the program will be provided through a High-Energy Aerobraking "management oversight committee" comprised of representatives from the appropriate OAST discipline Divisions, and the Pathfinder Program Manger. Responsibility for Field Center assignments, project plan approvals, and funding allocations will remain with the RF High-Energy Aerobraking Program Manager. For each phase of the program, a lead Center will be assigned and a Technology Project Manager appointed at that lead Center. Technology project planning, integration, and reporting will be performed by the lead field Center Technology Project Manager. Figure 1.2 illustrates the Phase I High-Energy Aerobraking Program (and technology project) management structure.

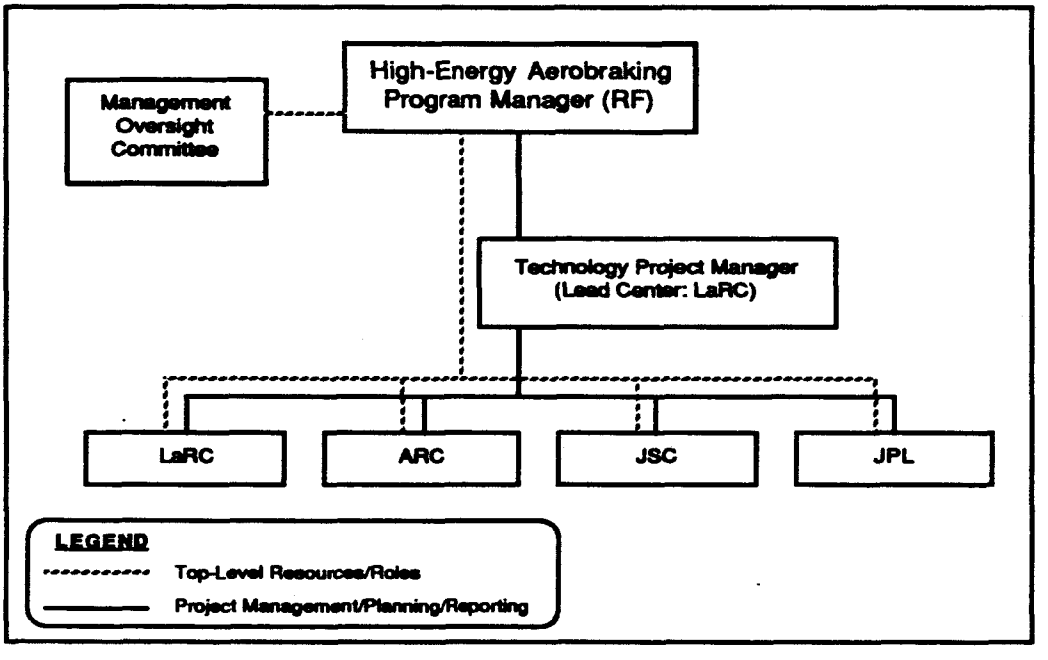


Figure 1.2 Pathfinder High-Energy Aerobraking Program Management Structure

## 1.3 Schedule and Deliverables

By the completion of Phase I, critical technologies will be developed to the point of defining reasonable margins in aerobrake configurations, aerodynamics, aerothermodynamics, flight mechanics and controls, and TPS designs. Improved computational flow codes for both Earth and Mars atmospheres, and engineering design and configuration optimization capability will be available. TPS design trades will be completed, and materials, cooling mechanisms, and structural concepts developed and evaluated. Advanced control algorithms will be established and adaptive GN&C systems validated. As a result of the above, baseline vehicle concepts, for both a piloted Mars mission and for an MRSR mission, will be defined.

At the completion of Phase II, all key high-energy aerobraking/aeromaneuvering technologies will have reach a state of maturity that will permit a high-energy planetary return flight experiment (PRFE) to be defined and conducted. To the greatest extent possible, this experiment will be built on the Civil Space Technology Initiative's (CSTI's) Aeroassist Flight Experiment (AFE). This will include AFE experiences, flight data, and where appropriate, flight hardware and instrumentation. The design, development, and support (i.e., optimized aeroshell designs, selection and development of flight instrumentation, etc.) for a planetary aerobraking experiment to "piggyback" on the MRSR mission will be completed during Phase II of the program.

A detailed five-year schedule associated with Phase I technology development is provided in Section 5. Five-year milestones from that schedule, including FY 1989 milestones are listed in Table 5.1. Figure 5.2 provides a top-level schedule for a projected two phase, 10-year High-Energy Aerobraking Program.

## 1.4 Resources

Resources requirements, including both funding and NASA workforce for the first five-years (i.e., Phase I, technology development) are provided in Table 1.2. Estimated funding levels required to support the High-Energy Aerobraking Program through Phase II, technology demonstration/flight experimentation, are provided in Table 1.3. Resources as currently allocated in the Pathfinder Program Plan do no support the Phase II program.

# SECTION 2

# INTRODUCTION

## 2.1 Pathfinder Program Overview

Pathfinder is a National Aeronautics and Space Administration (NASA) initiative to develop critical capabilities to support the future of the U.S. civil space program. Pathfinder does not, in itself, represent a commitment to any particular mission. However, through Pathfinder NASA's Office of Aeronautics and Space Technology (OAST) will develop a variety of high-leverage technologies that can be applied to a wide range of potential future NASA solar system exploration missions. Pathfinder is organized into four research and technology program areas: (1) Surface Exploration, (2) In-Space Operations, (3) Humans-In-Space, and (4) Space Transfer. The High-Energy Aerobraking Program is one of the three sub-programs in the Pathfinder Space Transfer technology thrust. Additional information on Pathfinder can be found in the Pathfinder Program Plan.

## 2.2 Document Purpose and Scope

This document is the High-Energy Aerobraking Program Plan. The purpose of this program plan is to provide the scope, content, and long-range plans of the Space Human Factors Program. The objectives of this document are: (1) to provided traceability to mission-derived technology requirements, (2) to specify the top-level work breakdown structure, (3) to define technical goals and objectives for the program and its major work packages, (4) to define the management responsibilities and accountability, (5) to establish resource allocations, and associated schedules, milestones, and deliverables, and (6) to document long-range Pathfinder High-Energy Aerobraking program planning.

# SECTION 3

# HIGH-ENERGY AEROBRAKING PROGRAM OVERVIEW

## 3.1 Mission Studies and Technology Requirements

NASA's planning for the future exploration of the solar system include both piloted and robotic missions to Mars. The success of these mission will depend upon maximizing non-propellent mission mass in low Earth orbit (LEO), on the planetary surface, and for return to Earth. At each of these mission stages, total mission mass, and in particular non-propellent mission mass, is limited by current launch vehicle capabilities. A key, enabling technology to reduce propellant mass requirements is the development and use of aerobraking techniques rather than retro propulsion to achieve deceleration for orbit modification (transition from an elliptical transfer to a circular orbit) at Mars, as well as at return to Earth.

In the case of a sample return mission, the use of aerobraking at Mars reduces the mass requirement to be delivered to LEO by 50 percent over an all propulsive capture. The case of a piloted Mars mission is more complex and the mass savings depends on the mission launch date, and whether the vehicle is configured for zero gravity or artificial gravity. Given a zero gravity spacecraft configuration, the required mass-to-LEO for an all-propulsive mission would be 2-to-4 million pounds compared with 1-to-2 million pounds for an aerobraking mission. The mass savings (or increased payload) capability associated with aerobraking is therefore very significant.

In order to plan an aerobraking technology program, selected exploration mission scenarios must be examined in sufficient detail to determine specific operational and technology development requirements that will dictate the design of aerobraking/aeromaneuvering vehicle configurations. Various mission parameters such as allowable transit times, spacecraft thermal control, desired parking orbits, landing sites, time on planetary surface, required delivery masses, acceptable G-loads on the crew during planetary entry/Earth reentry following a long period of space flight, must be quantified as to their effect on the overall design and optimization of aerobrake configurations.

## 3.2 Technology Assessment

At present, no current validated aerobraking capability exists. The Apollo and Shuttle experiments, with a simple blunt configuration operating over a narrow reentry corridor, provides a very limited database relative to aeromaneuvering/aerobraking techniques. Establishing this capability requires that a number of critical technologies and key issues be addressed. Effects of long-term exposure to a thermal protection system (TPS) to the space environment have not been precisely defined. In addition, ablative and non-ablative TPS designs that will accommodate very high velocity and/or high enthalpy flow conditions have not been evaluated or developed. The ability to computationally simulate "new" atmospheric constituents such as carbon dioxide, nitrogen and argon have not yet been developed. In general, high-speed Earth reentry and Mars/planetary entry flight conditions must be better defined and understood.

The ability to identify and compensate for large variations and fluctuations, in both Earth and Martian/planetary atmospheric densities, is needed; but fault-tolerant, real-time, adaptive guidance, navigation, and control (GN&C) have not been defined or developed.

## 3.3 Program Goals and Objectives

The long-term goal of the High-Energy Aerobraking Program is: to develop and validate the key technologies needed to enable the use of aerobraking for robotic and piloted missions to Mars and other related exploration mission scenarios.

This goal will be achieved through the accomplishment of the following program objectives:

(1) Identify mission performance parameters/constraints and establish aerobraking technology requirements for planetary entry and high-energy Earth reentry.

(2) Develop advanced computational fluid dynamics (CFD) codes for prediction of aerodynamics and aeroheating environments for both planetary entry and high-energy Earth reentry conditions.

(3) Develop and validate fault-tolerant guidance, navigation and control (GN&C) technologies for planetary entry and high-energy Earth aerobraking.

(4) Define and evaluate advanced thermal protection system (TPS) materials, and aerobrake structure designs.

Overall vehicle configuration analyses and system design trades, which will be used to integrate discipline objectives, will be supported by appropriate ground-based experimentation. Baseline vehicle concepts for both a piloted Mars mission and a Mars Rover/ Sample Return (MRSR) mission will be defined.

In the long term, flight experiments - one to validate high-energy aerobraking at Earth return (i.e., Planetary Return Flight Experiment (PRFE), as well as possible collaboration on the MRSR mission to demonstrated planetary entry aerobraking - may be conducted. The program will thus provide flight verification of all key high-energy aerobraking technologies and establish an important fundamental database appropriate to a wide-range of aerobraking applications.

## 3.4 Technical Approach

The Pathfinder High-Energy Aerobraking Program will encompass a broad range of technical disciplines, each at varying levels of technology readiness and maturity. As a consequence, the technical approach to implementation will involve a family of related discipline-directed efforts, coordinated through a Headquarters/Inter-Center working group.

Fundamental research, in the areas of TPS and aero/aerothermodynamics, will be balanced against more focused efforts in GN&C algorithms and systems development.

Overall programmatic and technical coordination will be achieved through initial mission analyses and requirements studies , later evolving to detailed system design trades, and integration studies. These activities will lead to and support the eventual development and conduct of appropriate aerobraking flight validation experiments.

Critical technologies will be developed, to the point of defining reasonable margins, in configuration versatility, aerodynamics, aerothermodynamics, flight mechanics, and TPS. Improved computational fluid dynamic (CFD) flow codes for both Earth and Mars atmospheres and engineering design capability will be established. TPS design trades will be completed and materials, cooling mechanisms and structural concepts developed and evaluated. Advanced control algorithms will be established and adaptive GN&C systems validated. As a result of the above, baseline vehicle concepts will be developed, for both a piloted Mars mission and a Mars Rover/Sample Return (MRSR) mission.

The information obtained from the High-Energy Aerobraking Program, complemented by the data obtained from the Aeroassist Flight Experiment (AFE) sub-program of the Civil Space Technology Initiative (CSTI), will provide a significant generic database for all aerobrake applications. This program will validate predictive and analysis methods, and provide a fundamental understanding of aeroheating mechanisms that will be valid for future high-energy Earth entries. Likewise, advanced TPS materials, GN&C, and other technologies, will be validated by the data produced in the flight experiment(s). These technology developments are critical to future design and selection of such systems, and will directly influence the optimal choice of vehicle aerobrake size and configuration.

# SECTION 4

# ORGANIZATION AND MANAGEMENT

## 4.1 Overview

The High-Energy Aerobraking Program will be planned and implemented in two broadly-defined phases. The first will be a Technology Development Phase. The product of this phase will be the development and maturation of key technologies, the definition of selected aeroassist vehicle concepts and configurations, and the definition of required flight experiments. The second phase will be a Technology Demonstration Phase, culminating in the conduct of appropriate aerobraking flight experiments. (Phase I falls within the next five years, FY 1989 through FY 1993, and was budgeted in the FY 1989 Pathfinder Program Plan.) Phase II is projected as a technology demonstration phase, culminating in an appropriate aerobraking flight experiment(s).

## 4.2 Work Breakdown Structure

Phase I of the High-Energy Aerobraking Program is divided into four major discipline areas and the definition of potential flight tests. The major work packages are: (1) mission and vehicle concept studies, (2) aerothermodynamics, (3) guidance, navigation, and control, (4) materials and structures, and (5) flight test definition. Figure 4.1 provides an overview of the program work breakdown structure. As the program moves from Phase I into Phase II, the work breakdown structure (WBS) will change to reflect the changing nature and character of the program.

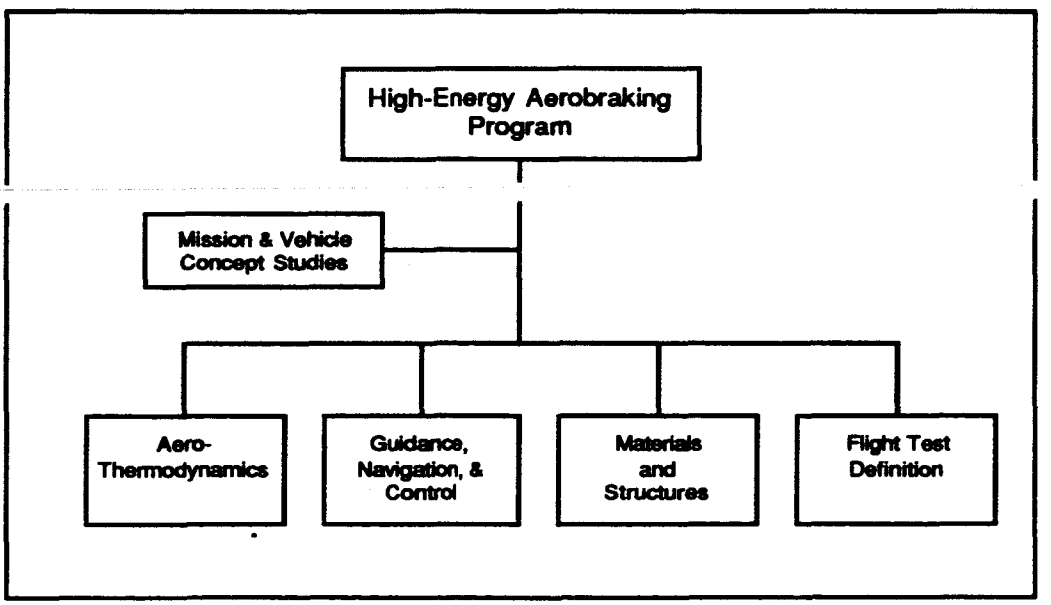


Figure 4.1 Pathfinder High-Energy Aerobraking Program Work Breakdown Structure

## 4.3 Management Structure

The High-Energy Aerobraking Program will be managed by a Program Manager in the Aerodynamics Division (RF) of the Office of Aeronautics and Space Technology (OAST). Coordination between the various discipline efforts within the program will be provided through a High-Energy Aerobraking "management oversight committee" comprised of representatives from the appropriate OAST discipline Divisions, and the Pathfinder Program Manger. Responsibility for Field Center assignments, project plan approvals, and funding allocations will remain with the RF High-Energy Aerobraking Program Manager. Figure 4.2 illustrates the Phase I High-Energy Aerobraking Program (and technology project) management structure.

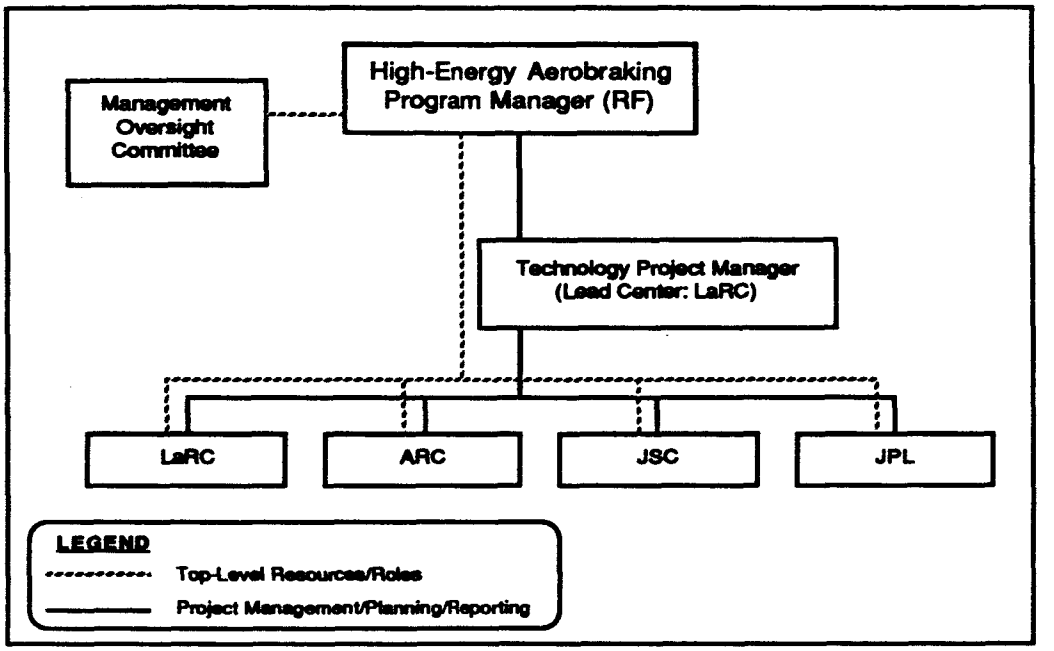


Figure 4.2 Pathfinder High-Energy Aerobraking Program Management

For each phase of the program, a lead Center will be assigned and a Technology Project Manager appointed at that lead Center. NASA Centers will be designated to implement specific tasks within the technology project. Technology project planning, integration, and reporting will be performed by the lead field Center Technology Project Manager. The Phase I Technology Project lead Center will be the Langley Research Center (LaRC). Participating NASA field Centers will include: LaRC, the Johnson Space Center (JSC), the Ames Research Center (ARC), and the Jet Propulsion Laboratory (JPL).

## 4.4 Program Coordination

Within OAST, the High-Energy Aerobraking Program will be technically coordinated in detail with the on-going CSTI AFE sub-program. This program will also seek

coordination with space computing technology developments. (This coordination, primarily with the OAST Information Sciences and Human Factors Division, "RC", will be important for aerobraking approaches that could require advances in real-time, on-board processing capabilities.) The program will also be coordinated with the OAST Propulsion, Power and Energy Division (RP) in the area of vehicle configuration definition.

Externally, this program will be generally coordinated with appropriate personnel in the Office of Space Flight (OSF). Also, in addition to mission analysis and requirements definition with the High-Energy Aerobraking Program, this effort will be coordinated with (1) piloted exploration mission definition studies of the Office of Exploration (OEXP) and (2) the MRSR mission study being conducted by the Office of Space Science and Applications (OSSA) Solar System Exploration Division (EL). Specific mission studies or opportunities for mission enhancements, through technology applications, will be recommended to those offices. Coordination will be maintained with the relevant aspects of the Department of Defense's (DoD's) programs.

Programmatically, the program will be coordinated with the other sub-programs in pathfinder through the pathfinder Program Manager and through the appropriate OAST sub-program managers. In particular, coordination will be maintained with the Autonomous Lander Program and the Autonomous Rendezvous and Docking Program.

## 4.5 Program Planning and Documentation

A detailed High-Energy Aerobraking Technology Project Plan will guide the five-year, technology development first phase of the effort. This plan will be developed and maintained cooperatively among the participating NASA field Centers and OAST. The lad Center will be responsible for coordinating the activity and producing the final document. The authority to resolve conflicts will reside with the RF Program Manager and the Headquarters "management oversight committee". The Technology Project Plan will determine exclusively program content, Center responsibilities, resource allocation, and milestones. The program will be formally reviewed each year. During these review, there will be an opportunity for each Center to participate within their particular areas of expertise, thus the project plan will be modified as required. A project plan for Phase II of the program (technology demonstration) will be developed at the completion of Phase I.

## 4.6 Program Reporting

### 4.6.1 Quarterly Status Report

Program reporting documentation will consist of, at a minimum, quarter technology project reports, submitted to the OAST HEAb Program Manager. These reports will track progress against Level 1 and Level 2 milestones and schedules. These reports will also identify and track any problems and/or issues, as well as potential corrective actions.

### 4.6.2 Annual Report

An annual report will be prepared by the lead Center, summarizing the year's

accomplishments and progress toward achieving approved technology performance objectives. The annual report will also identify key activities for the next fiscal year.

## 4.7 Advisory Committees and Working Groups

As with all sub-programs within the Pathfinder Program, the High-Energy Aerobraking Program will be subject to periodic reviews within the existing NASA Advisory Committee structure. Specifically, these reviews will include program status reports to the Space Technology Advisory Committee (SSTAC) on an annual basis. As noted previously, the program will be subject to top-level oversight and direction by the OAST HEAb Program Manager, working through the Headquarters management oversight committee. On occasion, ad hoc working groups may be formed to assist in the resolution of specific problems and/or issues.

# SECTION 5

# TECHNICAL PLAN

## 5.1 Overview

The High-Energy Aerobraking Program technical plan is organized according the program work breakdown structure (WBS). Figure 5.1 provides the current HEAb WBS.) It is divided into five major work packages that correspond to the four discipline areas, plus the "flight test definition" area.

Details of the content of each work package are provide in the Phase I, technology development, Technology Project Plan. This includes objectives, technical approach, description, schedule and milestones, deliverables, and resource allocations. Details regarding the overall technology performance objectives and technology readiness objectives are also contained the Technology project Plan. The following section provides a brief description of each work package area including potential task areas and sub-elements.

## 5.2 Mission and Vehicle Concept Studies

### 5.2.1 Description/Status

Studies that have been carried out to date indicate that for minimum-energy trajectories, reentry velocities will be approximately 12 km/sec for the MRSR mission, and approximate 14 km/sec for a piloted Mars mission. The MRSR studies have addressed the aerobraking phases of the mission (both Mars and Earth aerobraking) inconsiderable detail. Detailed studies of the aerobraking phases of a piloted Mars mission are needed. High fidelity aerodynamics and entry-heating analyses are needed for a piloted Mars mission. More detailed studies of the Mars orbit-to-Mars surface phase of a robotic MRSR mission are also needed, with emphasis on the applicability of moderate-to-high life-to-drag ratio (L/D) vehicles to Mars landing (i.e., aeromaneuvering vehicles).

Most studies performed to date have assumed either Apollo-type or biconic-type aeroshell vehicles. Optimum vehicle concepts have no yet been identified for either robotic or piloted Mars missions.

### 5.2.2 Work Package Tasks

The major tasks that will be performed as part of this work package element are:

1. Vehicle Concept Studies, including

   - Configuration Aerodynamics,
   - Approximate Heating ANalysis,
   - Thermal/Structural Concepts,
   - Aerobrake Vehicle/Transit Vehicle Compatibility,

- Entry Corridors and acceleration profiles,
- Multiple pass aerobrake, and
- Mars orbit-to-Mars surface and Mars ascent studies; *and*

2. Overall mission studies (complementary to OEXP studies).

## 5.3 Aerothermodynamics

### 5.3.1 Description/Status

Equilibrium forebody flow-field analyses are relatively advanced, but are applicable to a limited range of geometries (moderate angle sphere cones, spheres, ellipsoids, hyperboloids). Most sophisticate computational fluid dynamics (CFD) codes were developed for Jovian-entry (Galileo). Most Earth-entry analysis are old (circa 1970) and need to be updated. Nonequilibrium forebody analyses are presently undergoing rapid development for Lunar return-entry (AFE) conditions. Afterbody and (more importantly) complete forebody/afterbody flow-field analysis (except Galileo) involve only air with small ionization levels. The use of aerobraking in applications for planetary exploration, including Mars and other planets, will require a knowledge of the high temperature properties of other planetary gases, including significant ionization effects. In addition, state-of-the-art ablation product/flow-field interaction is in a relatively elementary state of understanding. More sophisticate analysis is required for successful planetary exploration. Figure 5.2 illustrates the large differences between AFE/Aero-Assisted Orbit Transfer Vehicle (A-OTV) flows and those for Earth-return aerobraking of a piloted Mars mission.

### 5.3.2 Work Package Tasks

The major tasks that will be performed as part of this work package element are:

1. Configuration Studies;
2. Algorithm/code development;
3. Properties of shock-heated air with moderate ionization;
4. Properties of shock-heated Mars atmospheric gases;
5. Ablation and ablation product/flow-field interactions;
6. Unsteady, turbulent flows;
7. Aerothermodynamics database and CFD code validation through appropriate ground and flight testing;
8. CFD analysis of facility flow conditions; *and*
9. Advanced instrumentation development and operation.

# SHOCK LAYER PHYSICS COMPARISON

OAST

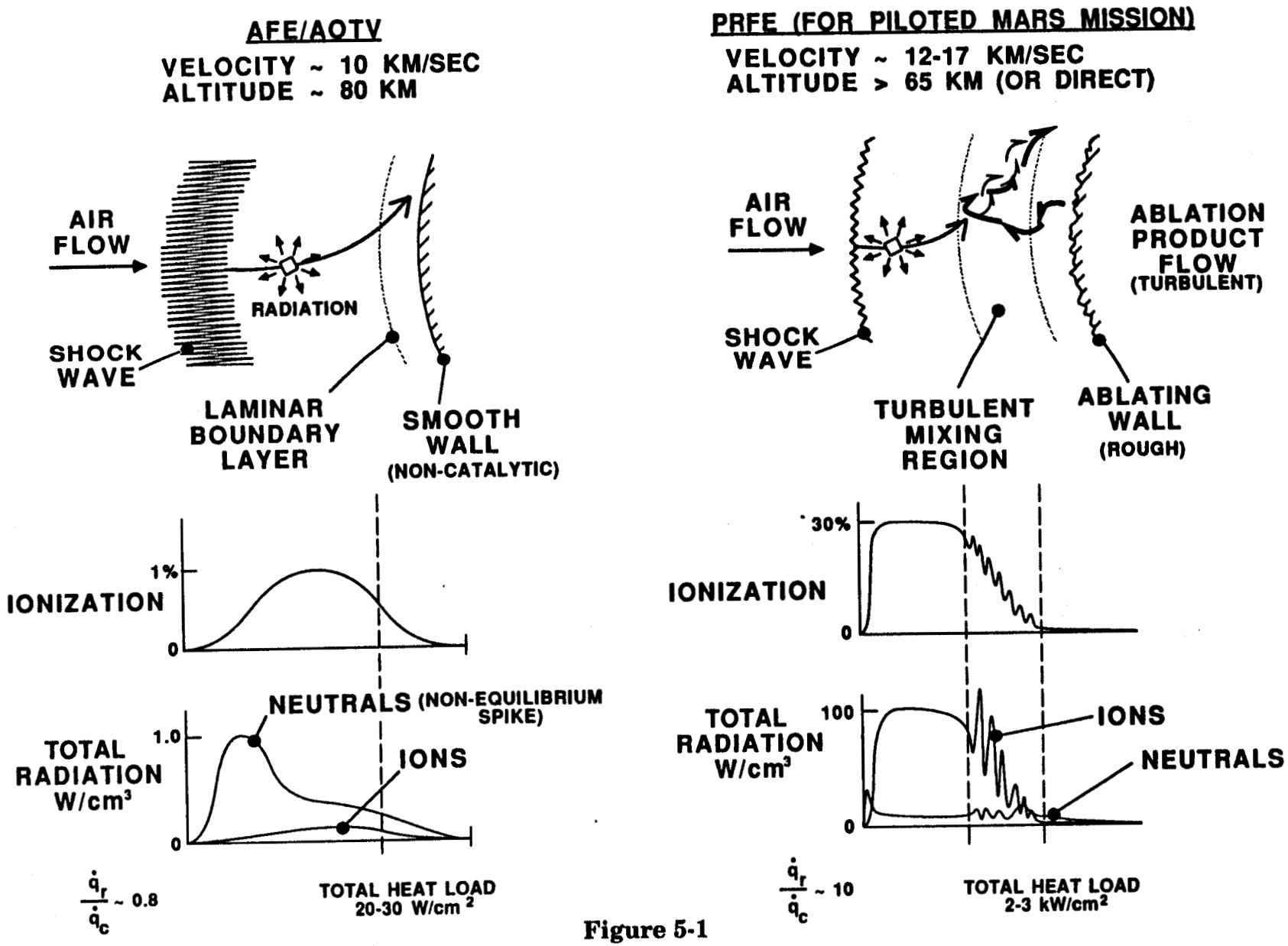


Figure 5-1

## 5.4 Guidance, Navigation, and Control (GN&C)

### 5.4.1 Description/Status

The literature contains a number of high-quality studies of GN&C for aerocapture missions dating back to the 1960s. The most recent studies address the GN&C aspects of aerocapture in considerable detail, and are associated with the MRSR mission. GN&C studies comparable to those done for MRSR concepts need to be carried out for piloted Mars mission concepts. The CSTI AFE studies are related, but have not addressed the high-entry velocities or the range of vehicle types pertinent to high-energy aerobraking. At present, the key issues appear to be: (a) navigation requirements for aerocapture, (2) planetary atmospheric uncertainties, and (c) the need for autonomous GN&C retargeting capability.

### 5.4.2 Work Package Tasks

The major tasks that will be performed as part of this work package element are:

1. Simulations of fault-tolerant avionics suite and software;
2. Navigation sensor and in-atmosphere assessments;
3. Aero control surface assessments;
4. Upgraded atmospheric modeling techniques;
5. Approach navigation accuracy requirements; *and*
6. Generic advanced guidance systems analysis.

## 5.5 Materials and Structures

### 5.5.1 Description/Status

Primary issues relate to TPS concepts. High-entry velocities during Earth return will probably necessitate ablative heat shields for high-heating-rate portions of vehicles. Significant portions of the vehicles may be protected with new, robust reusable insulators. Work started in the 1970's on reflective heat shields should be revisited. Technology advances during the past decade make this type of head shield more competitive that the "standard " heat shields.

### 5.5.2 Work Package Tasks

The major tasks that will be performed as part of this work package element are:

1. Structural design concepts, analysis, and optimization;
2. Development of advanced TPS materials, including

- Insulative (external/internal),
- Ablative (volume reflecting, noncatalytic, high-efficient transpiration (pyrolysis) cooled),
- Ceramics/ceramic composites;

2. Heat shield response analysis,

   - Catalytic effects, ablatores for Mars entry; *and*

3. Arcject and flight tests

   - New TPS materials and structures.

## 5.6 Flight Test Definition

### 5.6.1 Description/Status

Current studies show that Earth-entry aerobraking for a Mars return vehicle involves a much more severe entry environment than that associated with geostationary or Lunar returns. Not only are the aerodynamic heating levels high (by at least an order of magnitude), but also new phenomena are introduced that are not significant for lower velocity entries. For example, the high heating rates may well necessitate the use ablative heat shields which greatly complicate flow-field analysis through massive ablation product injection into the shock layer, mixing layer processes, and the possiblity of early transition to a turbulent mixing layer. It is clear that ihgh-energy aerobraking is sufficiently different from geosynchronous Earth orbit (GEO) or Lunar returns that it cannot be addressed through a simple extension of the CSTI Aeroassist Flight Experiment. (AFE is designed to obtain key flight data for Lunar and GEO return missions.)

The objectives of this task are to define the flight requirements and develop a test strategy for the verification of the high-energy aerobraking technologies. This task will asses the requiremetns of verification of the technologies and computer simulations beyond what is possible with wind tunnels, shock tubes, and arcjets. These requirements will be developed at both the systems level (e.g., heat shield integrity, guidance performance, etc). The definition of the test strategy will include an evaluation of the tset objectives with the test approach. The product of this task will be a definition of the high-energy aerobraking technology verification requriements in the form of flight test objectives and a flight test plan, including cost and schedule estimates). (During the latter portion of Phase I of this program. a proper "phase A" study of a PRFE will be conducted to achieve these objectives.)

### 5.6.2 Work Package Tasks

The major tasks that will be performed as part of this work package element are:

1. Research flight experiments,

   - Quantum steps in flow field and TPS,
   - Signficant steps in GN&C, and

- AFE philosophy;

2. Synergistic Pathfinder/MRSR technology certification flight concept;

3. Vehicle certification/technology validation flight,

   - coordinate with possible piloted Mars mission advanced technology development (ATD) program; *and*

3. "Piggy-back" technology experiment concepts as part of an early piloted Mars mission concept.

## 5.7 Five-Year Planning Summary

### 5.7.1 Schedule

By the completion of Phase I, critical technologies will be developed to the point of defining reasonable margins in aerobrake configurations, aerodynamics, aerothermodynamics, flight mechanics and controls, and TPS designs. Improved computational flow codes for both Earth and Mars atmospheres, and engineering design and configuration optimization capability will be available. TPS design trades will be completed, and materials, cooling mechanisms, and structural concepts developed and evaluated. Advanced control algorithms will be established and adaptive GN&C systems validated. As a result of the above, baseline vehicle concepts, for both a piloted Mars mission and for an MRSR mission, will be defined.

Thus, by the early 1990's, the key technologies needed to enable the use of aerobraking for robotic and piloted mission to mars and related mission scenarios will be developed and (to the extent possible) validated through ground-based expereimentation and simulations. In a related activity, by 1994, the AFE sub-program of CSTI will provide important aerobraking data. In addiont, flight tests (PRFE) that could provide conclusive verification of all key technologies will be defined. A detailed five-year schedule/milestone is given in Figure 5.2.

### 5.7.2 Milestones

Milestones for the planned five-year, Phase I of the Pathfidner High-Energy Aerobraking Program are provided in Table 5.1.

# HIGH-ENERGY AEROBRAKING
# 5-YEAR MILESTONE SCHEDULE

OAST

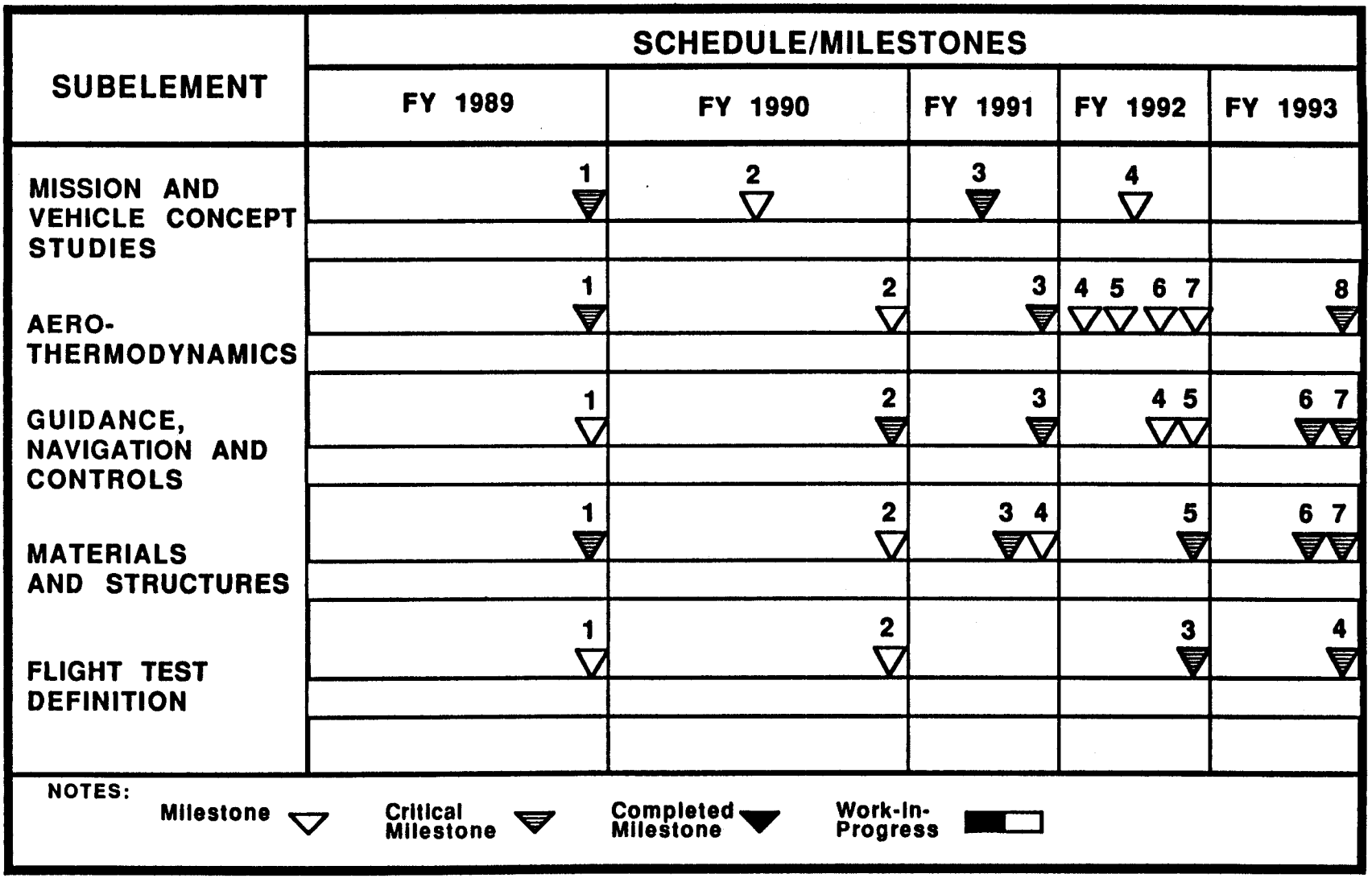


**Figure 1-3 PHASE I - TECHNOLOGY DEVELOPMENT**

SMW-0522

## HIGH-ENERGY AEROBRAKING

## FIVE-YEAR MILESTONES

### Mission and Vehicle Concept Studies

1. Definition of entry conditions, trajectory shaping, and candidate vehicle configurations for aerobraking at Mars and Earth.
2. Complete vehicle assessment for Mars orbit to surface payload delivery.
3. Complete parametric studies of aerocapture vehicle configuration effects on payload.
4. Optimal aerocapture vehicle design within constraints of heating, TPS, and G&C.

### Aerothermodynamics

1. Important flow phenomena defined.
2. Test facility instrumentation upgrade complete.
3. Algorithms developed for 3-D benchmark codes.
4. Wind-tunnel code validation data base complete.
5. Ablation model completed and coupled to flow-field codes.
6. Turbulence models incorporated into flow field codes.
7. Computational chemistry prediction of transport and radiactive properties complete.
8. 3-D benchmark codes complete and operational.

### Guidance,Navigation and Control

1. Preliminary GN&C assessments completed for MRSR mission (complements Code Z studies), Manned Mars Mission, and related Code Z mission scenarios.
2. Preliminary assessments completed for: (a) atmospheric navigation and guidance schemes; (b) multipass aerobraking; (c) impact of atmospheric and aerodynamic uncertainties; (d) GN&C laws; and (e) fault tolerance.

Table 1-1.

## HIGH-ENERGY AEROBRAKING
## FIVE-YEAR MILESTONES (CONT).

3. Initial unified simulation capability with advanced (real-time, adaptive, etc.) trajectory/GN&C algorithms.

4. Aerodynamic data base (from wind-tunnel and ballistic range tests) complete.

5. Fault tolerant avionics test bed operational.

6. Integrated autonomous approach guidance and navigation accuracies and computational requirements defined.

7. Integrated GN&C systems performance evaluated and fault tolerant architectures defined for MRSR, Manned Mars Mission, and related Code Z mission scenarios.

**Materials and Structures**

1. Complete evaluation of current AOTV TPS/structural design concepts for application to MRSR, Manned Mars Mission, and related Code Z scenarios.

2. Complete evaluation of insulator performance for Mars and Earth aerobraking/entry.

3. Experimental data base for ablation response and surface catalysis updated.

4. Coupled TPS/structure design code operational.

5. Updated ablation and surface catalysis analysis validated by comparison with experimental data.

6. Coupled TPS/structural design carried out for preferred vehicle concepts for MRSR, Manned Mars Mission, and related Code Z scenarios.

7. Advanced TPS (insulators, ablators, ceramic/ceramic) developed for MRSR, Manned Mars Mission, and related Code Z scenarios.

**Flight Test Definition**

1. Preliminary requirements assessment complete for Earth entry flight tests to address pivotal high-energy aerobraking technology issues.

2. Completion of feasibility studies of HEAB flight experiments carried out in conjunction with MRSR, Phobos, and other early missions.

Table 1-1.

3. Dedicated HEAB flight experiment defined.

4. Vehicle certification/HEAB technology validation flight test (carried out jointly with Manned Mars Mission Project) defined

Table 1-1.

## 5.8 Long-Range Program Plan and Options

At the completion of Phase II, all key high-energy aerobraking/aeromaneuvering technologies will have reach a state of maturity that will permit a high-energy planetary return flight experiment (PRFE) to be defined and conducted. To the greatest extent possible, this experiment will be built on the Civil Space Technology Initiative's (CSTI's) Aeroassist Flight Experiment (AFE). This will include AFE experiences, flight data, and where appropriate, flight hardware and instrumentation. The design, development, and support (i.e., optimized aeroshell designs, selection and development of flight instrumentation, etc.) for a planetary aerobraking experiment to "piggyback" on the MRSR mission will be completed during Phase II of the program.

Therefore, by the late 1990's, advanced computational and design techniques and their support ground-test database will be in place to support aerobraking mission design. Figure 5.3 provides a 10-year overview of the High-Energy Aerobraking Program, including high-velocity Earth entry flight tests.

# PATHFINDER
# HIGH-ENERGY AEROBRAKING

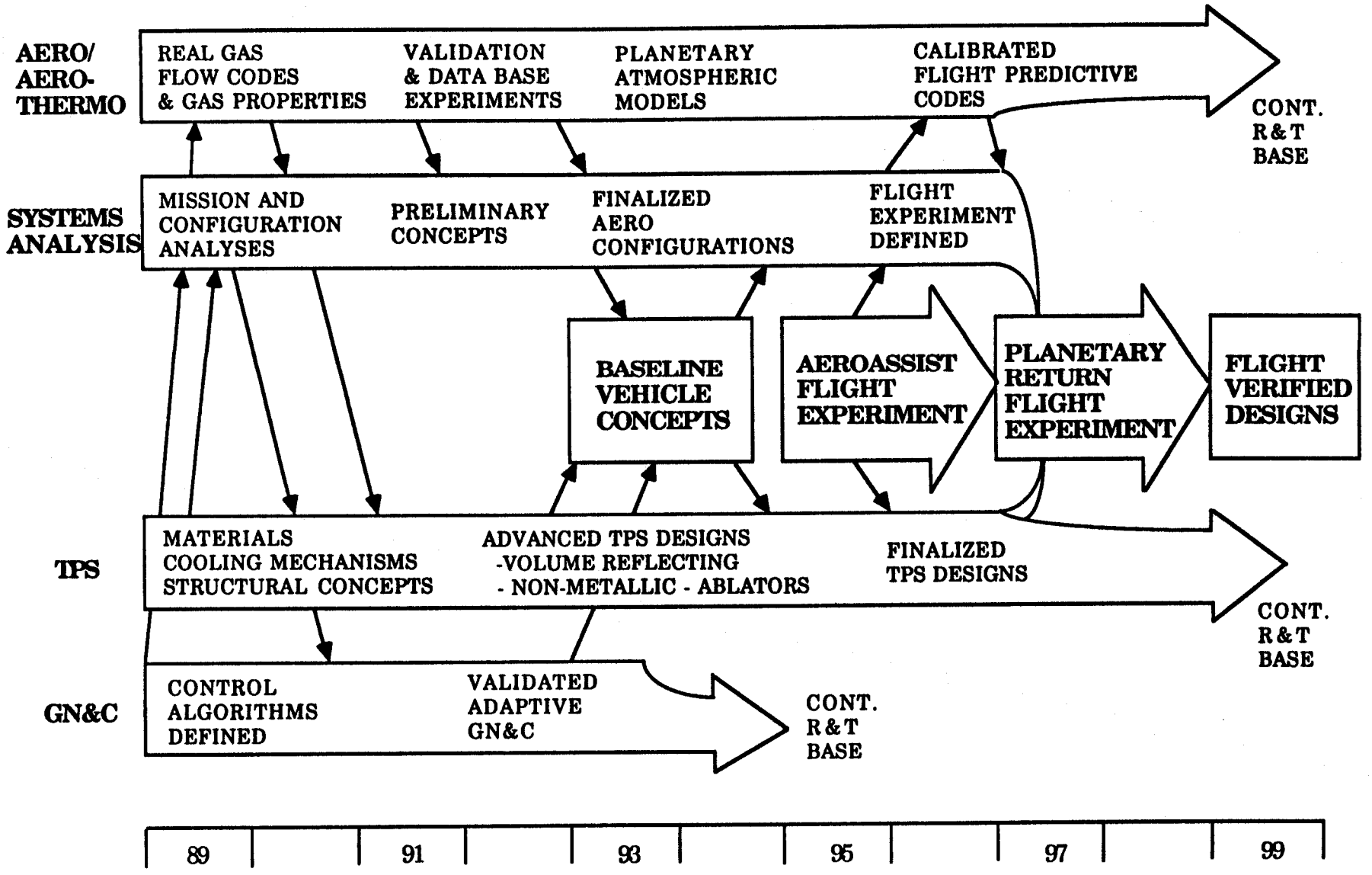


**Figure 1-2 HIGH-ENERGY AEROBRAKING 10-YEAR OVERVIEW**

# SECTION 6

# RESOURCES AND FINANCIAL MANAGEMENT PLAN

Resource requirements, including both funding and NASA workforce, for FY 1989 and the first 5 years of the program are provided in Table 6.1 and 6.2, respectively. A very preliminary estimate of funding levels required to support the High-Energy Aerobraking Program through Phase II, technology demonstration & flight experiments, is provided in Table 6.3.

Details of the FY 1989 and five-year are provided in the High-Energy Aerobraking Project Plan, including funding and workforce allocations for the individual work packages.

# RESOURCE REQUIREMENTS

# HIGH-ENERGY AEROBRAKING PROGRAM

| RESOURCES | SCHEDULE (FISCAL YEAR) | | | | |
|---|---|---|---|---|---|
| | 1989 | 1990 | 1991 | 1992 | 1993 |
| FUNDING ($,K) | 1.5M | 4.0M | 8.0M | 14.0M | 20.0M |
| NASA Workforce (WY/Year) | TBD | TBD | TBD | TBD | TBD |

Table 1-2 PHASE - I TECHNOLOGY DEVELOPMENT

| RESOURCES | SCHEDULE (FISCAL YEAR) | | | | |
|---|---|---|---|---|---|
| | 1994 | 1995 | 1996 | 1997 | 1998 |
| FUNDING ($,K) | 30.0M | 50.0M | 70.0M | 50.0M | 25.0M |
| NASA Workforce (WY/Year) | TBD | TBD | TBD | TBD | TBD |

Table 1-3 PHASE-II TECHNOLOGY DEMONSTRATION

# SECTION 7

# CONTRACTING STRATEGY AND PLANS

Details of Contracting plans and the distribution between in-house, university, and industry activities will be provided in the High-Energy Aerobraking Technology Project Plan. However, it is anticipated that the balance between in-house and outside research will favor contract and grant activities, with appropriate in-house support to be provided in key and critical research and test areas.

## SECTION 8

## FACILITIES STRATEGY AND PLANS

Details of facilites requiremetns, both computational and experimental/test, will be provided in the High-Energy Aerobraking Technology Project Plan. This plan will identify any new and/or signifcantly expanded ground test and flight research test capability that may be required to support the High-Energy Aerobraking Program.